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14. ABSTRACT
The proposal had three original objectives: (1) extension of central bottleneck models as the basis for computational models of sequence behavior, (2) emergent properties in scheduling behavioral sequences; and (3) optimising performance in sequence behavior. The objectives have broadened to include reinforcement learning in sampling spatially distributed probabilistic information sources. Not only is variability in the spatial distribution of information a central feature of many military environments (e.g., radar operations), its study will also serve as the foundation for generalizing results with linear scan paths characteristic of reading to fully 2-dimensional scans characteristic of knowledge intensive tasks, such as radar operations.

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AFOSR Scientific Officer: Dr. Jerome Busemeyer Jun Zhang

Title:

Human Resource Scheduling in Performing a Sequence of Discrete Responses

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Objectives

The proposal had three original objectives: (1) extension of central bottleneck models as the basis for computational models of sequence behavior, (2) emergent properties in scheduling behavioral sequences; and (3) optimising performance in sequence behavior. The objectives have broadened to include reinforcement learning in sampling spatially distributed probabilistic information sources. Not only is variability in the spatial distribution of information a central feature of many military environments (e.g., radar operations), its study will also serve as the foundation for generalizing results with linear scan paths characteristic of reading to fully 2-dimensional scans characteristic of knowledge intensive tasks, such as radar operations.

Status of Effort

The first year's efforts were focused on three principal objectives: (1) the role of preparation in observed data patterns, (2) learning to sample spatially disparate information sources based on reward patterns, (3) exploring just-in-time scheduling of central resources as an optimality criterion. Experiments examining the role of preparation investigated possible sources for the elevation of RT1, a significant emergent property seen in multiple response sequences that is not observed with single discrete responses. Experiments exploring learning and adapting to the relative information value of separate spatial locations provided initial insights into how behavior becomes optimised over time, and the resource demands of that learning. It will also provide the empirical basis for optimal models of behavior in a reinforcement-learning model. Computational modeling addressed the issue of optimal strategies by proposing a simple model for efficient regular saccades designed to minimize the variance in the eye movements and achieve a "just-in-time" scheduling of central operations. The central bottleneck has provided the cognitive architecture for existing models. Experiments are currently being designed to test the simple model and to relate the demands imposed by the task to the strategy adopted.

Accomplishments

Several key empirical results emerged from the experiments conducted in the first year. The role of preparation was addressed in two studies examining the effects of number of items, and eye movement requirements on RT1 elevation. No differences in RT1, IRI, or dwell time were found for either manipulation. If RT1 reflects preparation that preparation is not a function of sequence length or the presence of eye movements. RT1 elevation could represent a kind of "first-trial cost" as often observed in task switching studies. We are designing experiments to relate the two findings.

Alternatively, the cost could be related to initializing a sequence of actions irrespective of the number of items. Results of an experiment incorporating go and no-go stimuli in the trial sequence suggest this is one of perhaps multiple components to RT1 elevation. RT1 elevation was reduced by approximately 120 ms when the first item was a no-go stimulus (RT1 was made to the second item in the sequence). This suggests some component of sequence programming or initialisation plus a component due to response selection or retrieval. In a separate condition, we found

that RT1 was reduced by over 70 ms when subjects were instructed to respond to the first item only and ignore the rest, compared to a condition where they responded to the first item and were instructed to simply fixate the remaining items in turn. Interestingly, fixation durations for target items did not differ systematically with their position in the sequence. This is a pattern we have observed now in several experiments and points to a decoupling of fixations and manual responses under at least some conditions. There are interactions between neighboring items that are currently being explored both with computational models to examine possible pushback effects, and with further experiments. We are designing experiments to see how this pattern is altered as the complexity of the eye fixation pattern is varied and information sources are conditioned on prior reinforcement.

We have conducted an experiment varying the difficulty of items within a sequence. Here, as in reading, fixation durations are longer for the more difficult items, as is RT1. However, as in earlier experiments with blocked difficulty manipulations, the increase in fixation duration is less than the increase in RT. This result has also been noted in studies of eye movements in reading. Further experiments with varied difficulty under time pressure constraints will further probe these effects.

Several alternative computational models of the range of empirical findings have been developed and reported in the first year. All of them are variants of central bottleneck postponement models that differ in the control of saccade initiation. Models that assume a saccade is generated following a fixed stage of processing tend to produce constant eye-hand spans. That is, they fail to adequately decouple manual from ocular responses. As an alternative we develop a "just-in-time" model, which provided good fits to these data assuming subjects attempted to meet two optimization criteria: minimization of eye movement variability and a just-in-time scheduling of central stages to eliminate wait states or data storage. The minimum variance assumption captures the behavior of a simple automatic movement generator producing saccades without interfering with stimulus processing and without deliberate intent (central processor involvement). The just-in-time scheduling of central stages reflects an efficient saccade generator where the period of saccade generation is adapted to the overall information processing demands. That is, the model chooses a periodic movement that minimizes the overall time between successive central bottleneck stages. This simple just-in-time model provided good fits to the blocked difficulty data and was able to handle the go/no-go data by assuming that the no-go stimulus triggered a saccade as a response. Refinements of the model are in progress to account for the difficulty data.

The two modeling approaches adopted mirror the controversy in the reading and visual search literature over "process control" and "global estimation" models. Process control models assume that saccades are triggered by the completion of some processing stage. Global estimation models assume that the system adjusts the period over learning to keep fixation times approximately equal. It is clear that some knowledge of the state of internal processing is required to account for the increased duration of fixations on individual items. The issue is what information is used and how it is integrated with putative mechanisms that schedule periodic saccades. We are exploring extensions of existing ideal observer models of eye fixation location (e.g. *Mr. Chips*, Legge et al., 1997) to include timing of saccades. In addition, we are exploring reinforcement learning models to account for the fixation patterns in the

probability learning experiments, which have shown convergence of eye fixation on locations in accordance with their information value.

In the Pashler lab several studies have been conducted to examine the effects of reward gradients on spatial response selection. This has been studied using mouse movements in several different tasks involving different kinds of reward gradients. In some, there is an optimal x,y position which the subject attempts to locate using sequential mouse clicks (seeing a reward after each response). In others, there are two independent dimensions (time and space) being controlled, with individual reward values associated with each. One question concerned whether subjects could simultaneously update the temporal and spatial dimensions of their responses based on reward signals. To our surprise, it seems that this is possible. In another experiment, we are assessing reinforcement learning strategies, and hope to model the results using temporal difference learning (TD) algorithm. In recent work we have also extended the x,y task to oculomotor responses. So far it seems that while subjects response more quickly, the same basic strategies may be emerging. We hope to write up some of our initial results using the 2-dimensional adjustment task quite soon.

Personnel Supported

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Publications

NONE

Interactions/Transitions

a. Conference proceedings

Wu, S-C, Remington, R.W., Lewis, R. (2006) Modeling the scheduling of eye movements and manual responses in performing a sequence of discrete trials. In, *Proceedings of the 28th Annual Cognitive Society, Vancouver*, BC, Canada, July 26-29.

Remington, R.W., Lewis, R., & Wu, S-C (2006). Scheduling mental operations in a multiple-response sequence: Modeling the effects of a strategy to minimize variance in the timing of saccades. In *Proceedings of the 7th International Conference on Cognitive Modeling*, Trieste, Italy. April 2-6, 2006.

b. **Consultative and advisory functions:** Remington invited participant on DARPA panel to evaluate potential programs focused on human machine interfaces to distributed autonomous systems. June 2006, Washington DC.
c. **Technology assists:** NONE
d. **Discoveries, patents:** NONE
e. **Honors:** Remington awarded Australian Professorial Fellowship